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Renewable energy supply chain in Ostrobothnia region and Vaasa city: Innovative framework

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ABSTRACT

Energy and environmental technology is one of the most important debates among citizens and the government of Finland. As development of renewable energy utilization depends on geographical situation, the policy and strategic decisions of renewable promotion should focus more on regionals studies. Ostrobothnia and its capital Vaasa are among the best regions with high potentials of new renewable energy resources including wind power, smart grids, biofuels, and geothermal energy in Finland. However, high penetration of renewable energies creates challenges from supply chain viewpoint including environmental grid operators and maintain reliable service. This article discusses the development and performance of renewables supply chain in Ostrobothnia region and Vaasa city. The presented framework provides managerial insights to policy makers of governments and municipalities, as well as researchers and other stockholders to consider different aspects of diffusion of renewable energy technologies in the regional levels. The contributions are also beneficial for further studies related to renewable energy development, sources, carriers, and services.

Contents

1. Introduction

Although carbon-based fuels are the main source of power generation in the world, they are losing their advantages because of their limitations and environmental and economic concerns [1]. In response, utilization of domestic and local natural resources plays an important role among the various replacement strategies.

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Studies show that Finland stands among the countries with highest contribution of renewable energy resources (RER) in primary energy supply [2]. The country is also an early adopter of several alternative energy technologies especially biomass, wind, and hydropower. The main policy of the Finnish energy and climate sectors is to increase energy security by exploitation of renewable energy (RE) while reducing CO2 emissions.

As development of RE utilization depends on geographical potentials, policies and strategic investigations on RE promotion should focus more on regionals and locations level. In other words, regions with good potential of human and technological resources are in priority for RE development and investment. This is important especially in the countries with high authority of municipalities like Finland. Due to the focus of Finnish government to new RERs including wind, solar, and geothermal, investigations show that Ostrobothnia and its capital Vaasa are among the high potential regions for RE portfolio utilization [18].

This article reviews the supply chain of RE utilization in the Ostrobothnia region and Vaasa to identify the flow of RE promotion. The east cost of Bothnia gulf (Ostrobothnia) is one of the high potential locations for wind power generation in Finland. Vaasa is also one of the sunniest cities in Finland and the Nordic countries. On the other hand, largest Finnish energy technology companies that are also among the world's leaders are located in Vaasa (e.g., WARTSILA, ABB, SWITCH, and VACON). As technological development is a key diffusion driver of RE utilization, companies located in this region help to speed RE adoption plans and research. Indeed, Ostrobothnia and Vaasa have a large amount of university students compared to population (in the fields of energy technology and business) and the research facilities focus on increasing efficiency of the entire energy chain as well as promotion of RE utilization in the regional level. As research scholars create the first stage of a robust regional RE development, the number of research institutes related to this technology is an important factor for RE promotion [3,11].

Above issues show that successful investigations on diffusion of RE utilization in the regional level should concentrate on the supply chains of RE development. Therefore, our article is organized as follows: Section 2 gives a brief review of the Ostrobothnia region and Vaasa city. Section 3 reviews the important energy indicators in Finland and discusses role of RE in the Finnish policies and governmental supports schemes. Section 4 presents the innovative research framework to show domains and approaches of the RE supply chain in the regional level. Finally, Section 5 and related sub-sections consider RE supply chain in the Ostrobothnia region and Vaasa city from dimensions introduced in the Section 4.

2. Brief review of Ostrobothnia region and Vaasa city

Ostrobothnia (in Finnish: Pohjanmaan maakunta) is a region located in the West of Finland. The region is 2.35% of the Finland's area and has 3.31% of the Finland's population [4]. There are 16 municipalities in the region that Vaasa is the biggest and its capital with more than 34% of regions population. Compared to population and area, Vaasa is one of the most industrial and well-developed cities in Finland. Economic of Ostrobothnia is highly depending on its industrial products, in which about 70% of produced products are exported. This is more than 30% of Finland's energy technology exports [5]. Vaasa also consumes about 40% of the energy demand in Ostrobothnia. More than 150 companies are working in Ostrobothnia and Vaasa in the fields of energy and RE technologies. More than 10,000 staff are also working in the energy sector in Vaasa (companies and services) that compared to population (57,000) is one of the top regions in the world. The plan is to increase staff to 20,000 in 2020 with development of energy companies and RE utilization. This facilitates the development of RE utilization and speed RE and smart energy development projects. In addition, Vaasa has more than 12,000 university students and two of the three Finnish companies with the highest levels of R&D investment are working in Vaasa (WARTSILA and ABB).

3. Energy indicators and role of renewable energy resources in the security of energy supply in Finland

The industry sector consumes more than half of the primary energy in Finland. As this country is highly dependent to the external fossil fuels, risks appear arising from continuous fluctuations in energy prices as well as permanent increase in other costs such as transportation [6]. Although there are several solutions to

Table 1
Some policies and support schemes of RE promotion in Finland [14].

Support schemes
Investment supports
Developing storage capacity
R&D supports related to RE technologies and energy efficiency
Tax incentives for electricity generation from RERS
Feed-in-tariffs
Taxation of fossil fuels



Fig. 1. Location of Ostrobothnia and Vaasa in Finland.

respond to the challenges, diffusion of RE utilization is one of the main policies of the Finnish government.

As of 2011, about 31% of the global final energy consumption came from renewables in Finland [7]. The most important energy resources are nuclear power, hydropower, coal, natural gas, and biomass fuels (e.g., wood and peat) [8]. Although new RERs including wind, solar, and geothermal have small shares but some such as wind power and heating with geoenergy (geothermal energy) are rapidly growing. The country is also a part of common Nordic electricity market and Nord pool spot (largest electricity market in the world) [9]. Based on the Nord pool spot, electricity is traded in two markets: Elspot (day-ahead market) and Elbas (intraday market). Approximately 120 companies with more than 400 power plants are generating electricity that about 205 of them (power plants) are hydropower plants [2]. The government's target is to increase the share of RERs utilization especially wind power. To achieve the target, different policies and support schemes have been provided (Table 1) [14].

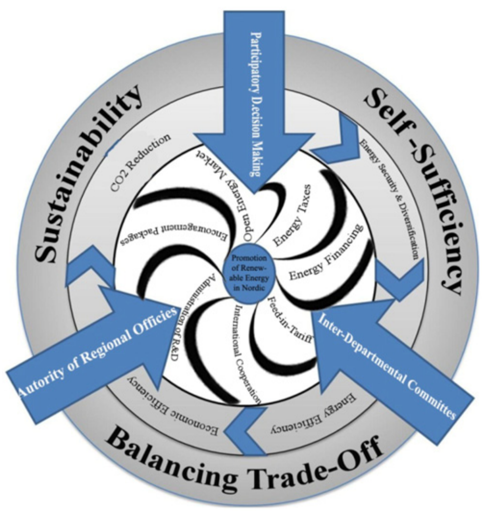


Fig. 2. Layers of RE development in the Nordic countries and Finland [20].

A study describes different layers of RE development in Finland and the Nordic countries (Figs. 1 and 2) [20]. These layers create a portfolio of political, technological, managerial, social, and cultural issues. Table 2 summarized the identified layers and their related schemes.

4. Renewable energy supply chain in Ostrobothnia and Vaasa: framework

Supply chain is all those activities and processes from exploitation of raw materials until the end use of products by consumers to provide a service/product for end-user. In general, supply chain consists of suppliers, producers, distributers, logistic service providers, retailers, and end-users [10]. Typical elements of supply chain include physical, information, and financial flows [3]. Due to the dominant business models in the Finnish RE industry, the framework of RE supply chain in Ostrobothnia and Vaasa is conceptualized as Fig. 3. This framework helps researchers and policy makers to identify and reduce the risks inherent in development process of RE utilization. According to figure, RE supply chain is characterized from two sides: domains and approaches. The domains cover the process of RE chain from resources to end-users. They create opportunities for business activities and are introduced in five main domains (Figs. 3 and 4).

The approaches of RE supply chain show different aspects of RE supply chain process from engineering, social, and management science. They cover all necessary elements of supply chain management. The first approach, policies and strategies, takes into account the role of municipalities and government on diffusion of RE in the region. Creating a development road map for each domain of RE chain and introducing supportive schemes (e.g., subsidies and taxes) are two subjects that are discussed in this approach.

Table 2
Different layers of strategic analysis of diffusion of renewable energy in Finland and the Nordic countries.

Layer	Description	Sub-layer	Aim
Dimensions	To show the purposes of diffusion of RE utilization	Self-sufficiency	To reduce consumption of fossil fuels and increase the dependency of indigenous resources
		Balancing trade-off	To help to economic and technologic growth of the regions
		Sustainability	To reduce pollution and environmental impacts
Characters	To identify main stakeholders affect public policies and process of decision-making	Participatory decision-making	To have the supports of the community organizations and citizens
		Inter-departmental committees	To have a comprehensive and coordinative decision making
		Authority of regional offices	To increase the role of regional s (municipalities) in decision-making
Objectives	To show different perspectives of diffusion of RE	Energy security and diversification	To reduce the dependency to the external resources(energy imports)
		Energy efficiency	To produce specific amount of services using less energy
		Economic efficiency	– Technical efficiency – Allocative efficiency
		CO2 reduction	To minimize CO2 emissions from fossil fuel burning caused by human activities
Key schemes	To describe different policies or regulations related to diffusion of RERs utilization	Energy financing	To direct government investment on the RE technologies and efficiency solutions
		Energy taxes	To curb the growth of energy consumption
		Open energy market	To make RE utilization competitive
		Encouragement packages and green certificates	To improve the knowledge and awareness of the citizens about RERs
		Administration of research	To manage research and R&D funds
		International cooperation	To share and crate the knowledge
		Feed-in-tariff	To accelerate investment in RE utilization

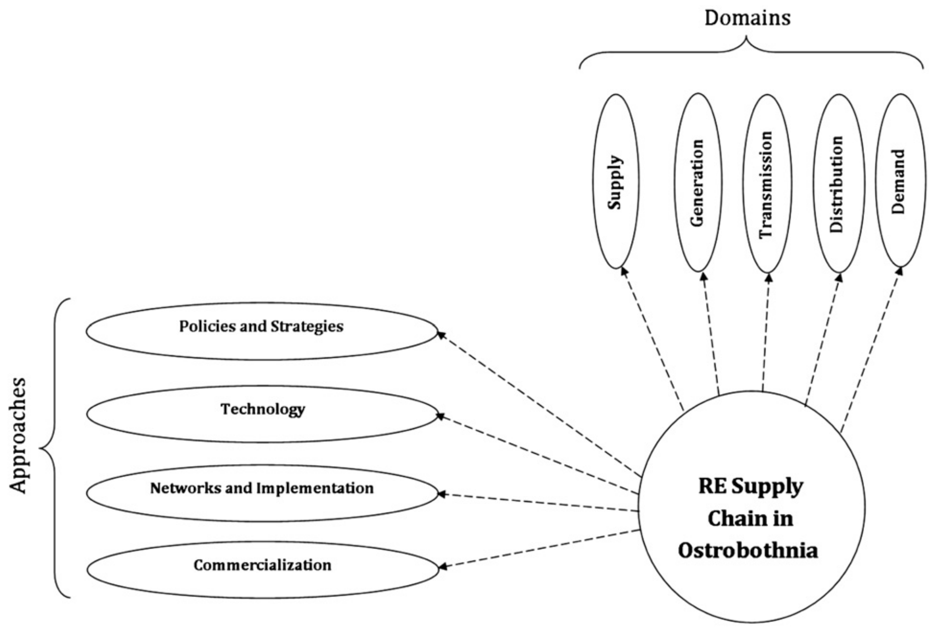


Fig.3. Framework of RE supply chain in Ostrobothnia and Vaasa.



Fig. 4. Domains of RE supply chain.

The approach "Technology" examines the ways to provide a successful use of RERs in the region. Evaluation and analysis of region's potentials in each domain from technological and infrastructure viewpoints are the focuses of this approach. "Networks and implementation" presents, analyzes, and designs high efficient performance of RE domains. Creating better value for customers and shareholders in each RE domains, quality of RE services, joint investments, and knowledge sharing with other regions are examples of this approach. Finally, "commercialization" includes the economic and investment issues of RE development in the region. Studies show that RE market is complex. In other words, while free market is encouraged in Finland, the government intervention or incentives should support new technologies and businesses in this market. To keep the research integration and due to the pages limitation, the approaches of RE supply chain are considered into each domain.

5. Domains and related approaches of renewable energy supply chain in Ostrobothnia and Vaasa

The process of renewable energy supply chain includes five main domains showed in Fig. 4.

5.1. RE supply in Ostrobothnia

The first chain, supply, includes resources that can be utilized in Ostrobothnia. The previous studies of authors show that factors related to feasibility affect RERs utilization (e.g., availability, annual exploitability, technologic and usage limits) [19,15]. Further, factors such as logistic possibilities and competition of a RER with other RERs limit use of a RER. In Finland, the main RE source is biomass and has a particular place in the energy policies. It made up about 86% of total RERs and 21.5% of total primary energy supply in 2009 [2]. While energy demand (heat and electricity) in Ostrobthnia was 4322 GWh/a, about 63% was supplied by RERs in 2006 [18]. Table 3 shows energy demand (heat and electricity) and share of RERs in Ostorobthnia and Vaasa in 2006 [18].

Table 3
Energy demand and share of RERs in Ostrobthnia and Vaasa [18].

Region	Energy demand(GWh/a)	Share of RERs (%)
Vaasa	1669	54
Ostrobthnia without Vaasa	2653	70
Total Ostrobothnia	4322	63

Most of the biomass resources (forest biomass) in Finland are distributed in 15 areas in Finland. Although the potential of biomass in the west coast is not rich as the center and east, biomass has a dominant share in energy demand in Ostrobothnia and Vaasa. However, biomass sources are not limited to forest biomass and utilizing biodegradable waste for electricity generation or heating production is also one of the potentials in Ostorobthnia. A new power plant that is being built in Mustasaari (in Ostrobothnia neighbor of Vaasa) is one of the last activities to convert waste into energy in the region. It starts officially to burn waste at the beginning of 2013.

The biggest bioenergy potential in Ostrobothnia region is about 1200 GWh in wood and 1000 GWh in straw [18]. About 500 GWh is the potential of wastes like manure, biowaste, sludge and other industrial wastes. Therefore, while biomass has about 2700 GWh energy potential in Ostrobothnia, energy demand is about 3000 GWh (without forest industry) [18]. This means with 90% energy conversion efficiency, about 80% theoretical self-support on this region can come by bioenergy.

The second important RE source in Ostrobothnia is wind power. Due to the coastline, wind energy has important role in power generation plans in Ostrobothnia and Vaasa by 2020(Fig. 5) [12,16]. Wind power not only is the fast growing source among other RERs, but also most Finnish wind companies are located in this region and Vaasa. Until 10.2012, the capacity of 146 wind turbines was

238 MW that shows a growth of 10% in the capacity in just six months [17]. The Finland's objective is to increase the installed wind turbines to approximately 2000 MW by 2020 [2]. The current capacity of wind power in Ostrobothnia is about 8.75 MW [17].

Although about 205 hydropower plants work in Finland and have a share of 15% in total primary energy supply, the hydropower has not commercial potential in Ostrobothnia because of outstretched situation. As most of the Hydropower possibilities have been already used (just in small scales), this source has little potential for development in Finland.

From solar energy supply, Ostrobothnia is one of the sunniest cities in Finland with more than 1900 sunny hours/year [2]. Based on geographical condition, Ostrobothnia is the best place for solar energy utilization in Finland and even in the Nordic countries especially in the summer months (June until August) that the daylight is more than 20 h. Specifically, as summer cottage is an important part of Finnish culture (especially in June and July) solar energy can play an important role to respond the energy needs in the cottages [2]. However, the potential of solar energy in the Nordic region cannot compare with south and even center of Europe.

Finally, geothermal energy and heat pumps have good utilization potential especially for space heating and cooling, and hot water heating in single-family houses. The sources of this energy are boreholes, surface sediments in Bothnia gulf and lakes. In a larger scale, a low energy network was taken to utilize sediments of the seabed to produce heat in the Suvilahti residential area in Vaasa in 2008. This energy network is one of the first such used technologies in Finland to take off.

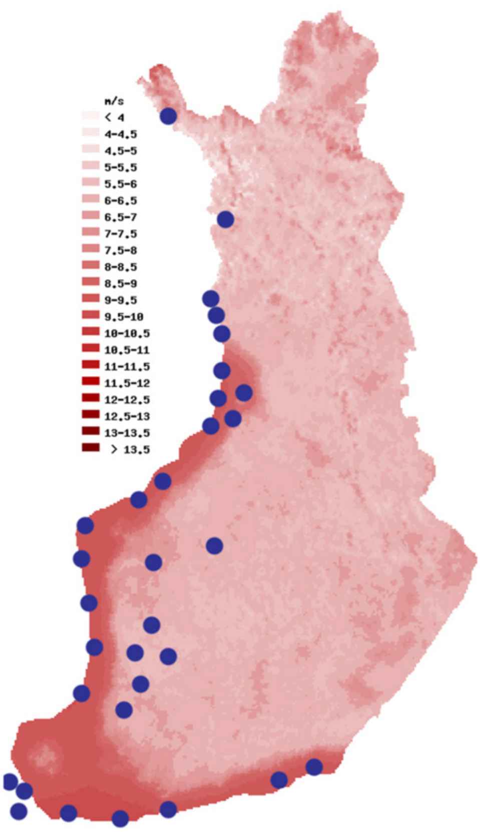


Fig. 5. Potential of Wind power and wind turbine sites in 6.2012[16] [17].

5.2. RE generation in Ostrobothnia

The second domain of RE chain is generation that is sometimes called production. Factors such as location, investments costs, operation costs, conversion efficiency, technology limits, and manpower are the effective issues in this domain and its related approaches. As discussed in 5.1., wind and biomass are two sources with high potentials for development in Ostrobothnia. Figs. 6,7, and 8 illustrate the simple process of energy generation/production for each named RER. The first part of these figures shows details of RERs in Ostrobothnia and Vaasa. The second part indicates the conversion process or primary outcomes. The last part of the process also illustrates the outcomes that are valuable from market and demand side. The demand side includes residential and commercial sector, industrial sector, transportation sector, and electric power sector.

There are a lot of energy manufacturers or engineering-service companies located in Ostrobothnia and Vaasa especially in wind power technology. More than 150 companies related to RE industry are working in Ostrobothnia and some such as ABB, SWITCH, CITEC, and WARTSILA are among the world's leaders.

5.3. RE transmission and distribution in Ostrobothnia

Electric power transmission establishes an important part of RE supply chain in Ostrobothnia. It covers the transport of electric energy generating power plants to loads that interconnects

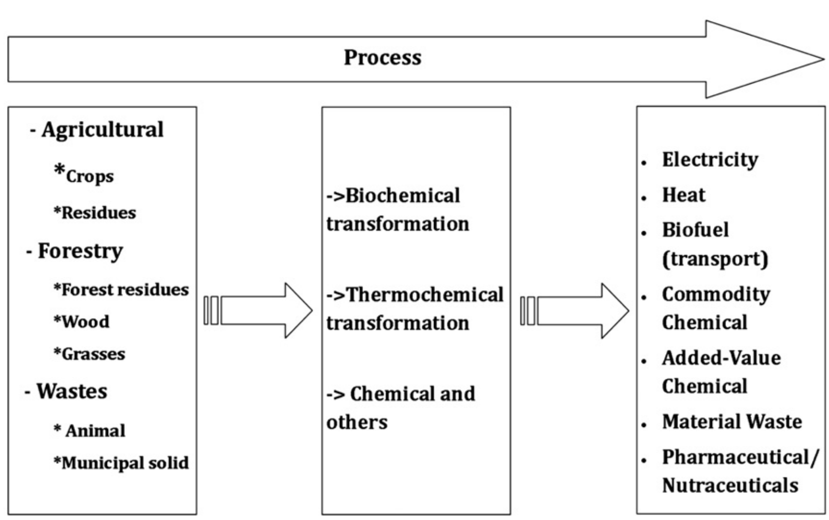


Fig. 6. Simple process of Biomass conversion technology.

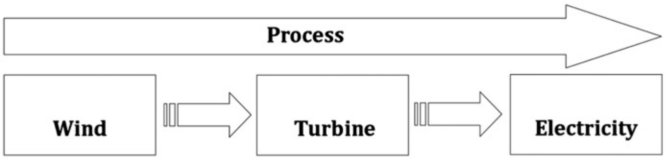


Fig.7. Simple process of wind power generation flow.

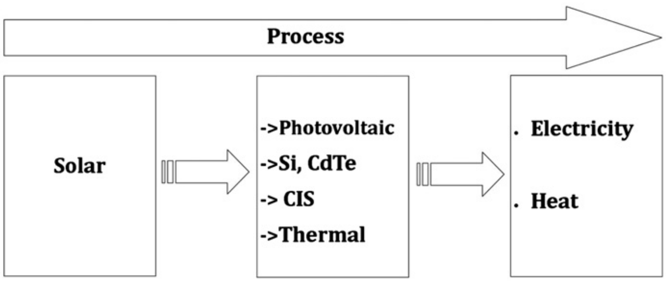


Fig. 8. Simple process of solar energy generation.

generators and loads and provides multiple paths among them. Electricity applications in Finland are not limited for lighting, refrigeration, washing and drying, and miscellaneous electric loads. Electricity is the main source of family heating and cooking systems too. Energy distribution also refers to different power generating or transmission technologies that could be combined with load and storage systems to improve the quality of electricity supply chain [13]. It encompasses variety of technologies, including RE distribution, such as wind turbines, solar power, micro turbines, fuel cells, load reduction technologies, reciprocating engines, and battery storage systems.

RE distribution has an important role in energy supply chain especially in the future plans of Finland. Improving energy security, reducing the fluctuations of electricity price, mitigating congestion in transmission lines, and providing greater stability in the electricity grids are examples of an efficient RE distribution system. RE transmission and distribution in Ostrobothnia are currently linked with traditional energy networks to support regional power needs. Since a significant share of generated electricity by power plants is lost before to reach to end-users, the Finnish government has supported related research projects and technologies to improve the efficiency of electricity networks (e.g., low-loss transmission technologies, controlling the systems of distribution, and reliable systems in the regions).

RE distribution can be as a complex system integrated with the electricity grid (including electricity/thermal generation, storage, and energy management) or a small or stand-alone generator to provide backup power at an electricity demand side. The small-scale generation (on-site power generators) can be owned by end users (consumers), the utility, or a third party. The energy distribution network in Finland and Ostrobothnia is turning into market place for decentralized energy production. Indeed, due to the importance of CHP (combined heating, and power) plants in the energy system in Ostrobothnia (and Finland), lean distribution technologies affect efficiency and energy costs of CHP applications.

As RE coupling with other distribution networks is a challenging process especially to balance the demand fluctuation within a period of time or to balance the intermittent or variability of RE resources, some projects like smart grids have been introduced to improve the efficiency of the networks in Ostrobothnia. The Smart grids project covers all aspects from energy production, transmission, and distribution to energy efficient building automation. It is also improving the maneuverability of power generation to the rapid response to demand even beyond the Ostrobothnia's boundaries. In this way, role of energy technology companies working in the region is completely significant to support and speed development plans. An example is ABB that supports technologies of remote monitoring and control, and automatic connections in the smart grids project in Ostrobothnia.

5.4. RE demand in Ostrobothnia

Energy demand is the amount of energy should be managed in different appliances within industries, transport, housing, etc. RE demand in Ostrobothnia have two major markets: electricity and heating (Table 3). Consumption market in Ostrobothnia is highly influenced by the economy situation and the weather. In good economic years and in colder winters electricity or heating demand is higher.

The electricity utilized from RE are distributed by service providers or retailers to the end users. There are two different electricity sales contracts in Ostrobothnia: green electricity and normal electricity (nuclear or other resources) that customers can select and. Despite all governmental supports (subsides and taxation), the electricity generated by RERs (green electricity) is still more expensive compared to normal electricity. Local energy companies are responsible for retail selling of electricity and some of them like Vaasan Sahko Oy have customers from locations outside of Ostrobothnia and Vaasa. As discussed in 5.3, small-scale renewable heating and cooling systems have been recently considered as new markets. The size of these systems ranges a few kilowatts to1 MW. Therefore, end-users can utilize RERs for their domestic usages such as heat pumps etc. As Fig. 9 illustrates, the demand side is not limited to the end-users. It covers other aspects of supply and includes a portfolio of products and services. Costs, government policies, substitution effect, and social and environment impacts are the most important concerns that exist from demand side of RE supply chain [3,10]. For instance, customer's willingness to buy a RE product or a service with lower price is an important issue that specially show itself in the competitive situations such as economic crisis and auctions. As geothermal, wind, and solar technologies are not mature in Finland, further cost reductions can be expected with technology development.

6. Discussion and conclusion

Utilization of RERs creates challenges in different areas from exploration to managing networks and demand side. One of the important but new disciplines in diffusion and adoption of RE

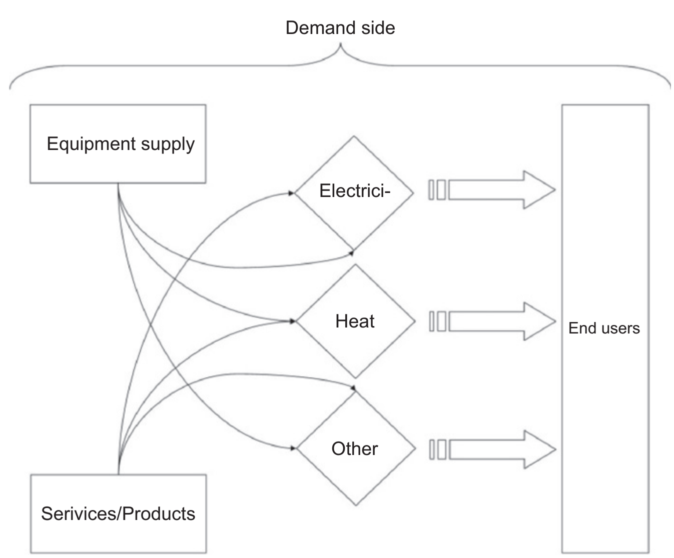


Fig. 9. Demand side of RE supply chain in Ostrobothnia and Vaasa.

utilization is RE supply chain. This study discussed RE utilization from supply chain viewpoint in Ostrobothnia and Vaasa. The work also showed how different domains and approaches help policy-makers to promote RE technologies in the regional or provincial scale. Given especial focus of Finnish government in new RERs including wind, solar, and geothermal, Ostrobothnia and Vaasa are good alternatives for RE investments in Finland.

Despite the successes, there are still shortages in the plans, process, and achievements of RE development in well-developed regions such as our case study. For instance, the necessity and role of local energy research centers and institutes in regional RE development is very important and they should have authority to manage and lead RE research and projects (from both commercial and technological aspects). On the other hand, new methods and technologies of RE utilization should be more considered in the policies of energy development. As an example, while 50% of wastes are utilized as energy in Sweden, about 10% are utilized in Finland. It seems Finland and Ostrobothnia need more attention to such development policies. In case biodegradable waste, since Ostrobothnia is one of the high developed and rich regions from social and economic indicators, the consumption and thereby amount of waste is high. Thereby, development of private waste power plants should be considered in the development policies of municipalities. Indeed, as geothermal energy has good potential in heating and cooling of large buildings (e.g., block of flats, schools, and libraries), polices should considered more to commercial aspects of this source.

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